

Historical Seismicity in the Central Highlands, Passamaquoddy Bay, and Moncton Regions of New Brunswick, Canada, 1817–1961

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ABSTRACT

A study of the historical seismicity of New Brunswick has been made by scanning weekly local newspapers from the early 1800's to 1961 for references to possible earthquakes. Lateral searches of other contemporary newspapers and diaries were also made for the dates of newly found events and for earthquakes listed previously in the Canadian Earthquake Epicentre File (CEEF).

Three regions of enhanced activity were identified: the Central Highlands (Miramichi) subzone, the Passamaquoddy Bay subzone, and the Moncton subzone. From the scanning process, eleven previously unlisted earthquakes were found in the Central Highlands region and parameters of nine events listed in the CEEF were found in need of revision. An additional eleven previously unlisted earthquakes were found in the Passamaquoddy Bay region by the scanning process and parameters of 26 CEEF-listed events needed revision. The Moncton region shows the least activity, with six additional unlisted earthquakes being found by the scanning process and parameters of two events listed in the CEEF needing revision. The study showed that some earthquakes listed in the CEEF had been mislocated and that other events listed as earthquakes were actually explosions or meteorological effects, such as cryoseisms or thunderstorms.

Data from an instrumentally recorded earthquake in 1999 in the Passamaquoddy Bay region showed that the magnitude based on the area where the earthquake was felt exceeded the instrumentally determined magnitude by 0.9. Caution should therefore be exercised in applying felt area–magnitude relationships to small earthquakes.

INTRODUCTION

Most of New Brunswick lies within the northeastern corner of the Northern Appalachian Zone, as plotted on a map on the Web site of the National Earthquake Hazards Program of the Geological Survey of Canada (http://www.seismo.nrcan.gc.ca/historic_eq/eastcan_e.php). An edited copy of this map

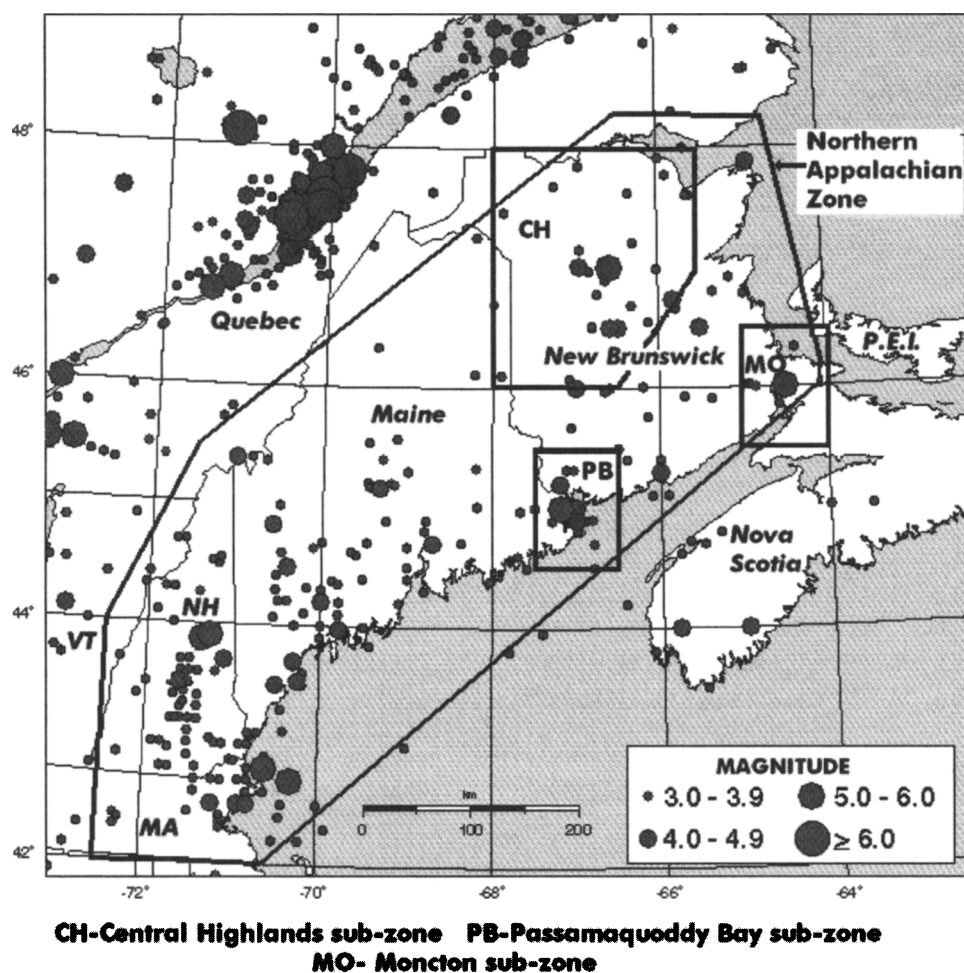
is shown in Figure 1. Within this zone, the province has experienced four historic earthquakes in the magnitude 5 to 6 range, in 1855, 1869, 1904, and 1982. Three aftershocks of magnitudes 5.0, 5.1, and 5.4 were associated with the 1982 earthquake. A small area of the northwestern part of the province, with a few low magnitude earthquakes, lies within the Eastern Background Zone.

The historical seismicity of New Brunswick was investigated previously as part of a much larger study for eastern Canada and adjacent parts of the USA by Smith (1962, 1966), using the archived resources compiled by previous seismologists and the historical resources then available in Ottawa. Some of the historical earthquakes of the region have also been considered in a study of the relationship to geological structure by Rast *et al.* (1979), in a review of seismicity of the Maritime Provinces by Burke (1984), and in an investigation of the four largest earthquakes that have occurred in Maine and New Brunswick by Leblanc and Burke (1985). A comprehensive computer list of Canadian earthquakes is maintained by Earthquakes Canada of Natural Resources Canada as the Canadian Earthquake Epicentre File (CEEF).

It might therefore appear that the investigation of the historical seismicity of the region is complete. As part of another study, however, references were found in local newspapers to earthquakes that were not listed in the CEEF. Other accounts suggested that revisions were necessary to the epicenters, magnitudes, dates, and times of some listed events. A decision was then made by John Adams of the Geological Survey of Canada to fund investigations of the local archived resources available in New Brunswick, which resulted in the collection of the data that form the basis of this paper. More detailed accounts of the searches of the historical sources for New Brunswick can be found in the following contract reports: Burke *et al.* (1985), Burke *et al.* (1987), Burke *et al.* (1988), and Burke *et al.* (1990). Similar investigations were instigated at the same time for the provinces of Québec, Newfoundland, and Nova Scotia (Gouin, 2001; Staveley, 1984; and Ruffman and Peterson, 1988, respectively).

In that part of New Brunswick contained within the Northern Appalachian Zone, earthquake epicenters cluster in three regions: the Central Highlands (Miramichi) subzone, the Passamaquoddy Bay subzone, and the Moncton subzone

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▲ **Figure 1.** Location map. (Earthquake epicenters from CEEF. Figure slightly modified from map provided by S. Halchuk, Geological Survey of Canada, written communication, February 2003.)

(Figure 1). Historical reports of earthquakes in these regions between the early 1800's and 1961 were investigated in the present study. Information on each event has been evaluated to decide if it represents an earthquake or some other phenomenon. For those earthquakes for which reports were available from more than one location, felt and intensity information were plotted on a map and felt area magnitudes and epicenters were determined.

STUDY OF NEWSPAPERS AND HISTORICAL DOCUMENTS

The search for previously unlisted earthquakes was based on the scanning of newspapers published in the province of New Brunswick. Weekly newspapers were selected on the basis of the extent of their coverage of regional and local news and their availability on microfilm. Each issue was scanned for articles that referred to events described as earthquakes or that had characteristics similar to earthquakes, and the date of each reference was noted. Particularly in the early years of the nineteenth century, gaps occurred in the publication or pres-

ervation of issues of the selected newspapers. Other newspapers, if available, were then consulted to cover these gaps.

Lateral searches of all available newspapers were made for a month of issues following the dates of previously unlisted events. These searches were complemented by searches of diaries and other historical documents which covered the dates of the events. The same procedure was also followed for earthquakes previously listed in the CEEF to see if additional information would lead to changes in any of their parameters.

Cryoseisms and Other Nonearthquake Events

From the lateral search results, it became evident that people would often mistakenly identify vibrations and sounds from other sources as earthquakes. For example, peals of thunder from a nearby storm might be reported as an earthquake, particularly if the storm did not pass directly over the reporting site. Also, local explosions might be mistaken for an earthquake. It is therefore essential that lateral searches investigate other possible origins of earthquake reports, especially if one is dealing with a report from a single location.

In the winter months, other meteorologically related phenomena have been mistaken for earthquake activity in

reports to newspapers. People report hearing sounds or feeling local vibrations, which they attribute to local earthquake activity. Many of these events turn out to be associated with freezing processes of the ground and are called cryoseisms, or, colloquially, "frostquakes." Open cracks in the ground and preserved remnants of displaced soft sediments caused by extreme freezing cycles can also be mistaken for deformation features caused by earthquakes.

An example of such a mistaken identification is the 26 January 1884 event listed as a 3.0 M_L earthquake in the CEEF. A lateral search of issues of the *Saint John Globe* after this date found the following account in the 28 January 1884 issue.

EARTHQUAKES AT ROTHESAY

The peaceful little village of Rothesay, situated on the Intercolonial Railway, a few miles from St. John, was invaded last night by two to three distinct shocks of earthquake, which not only disturbed the equanimity of the inhabitants but also shook several of their dwellings. A GLOBE reporter interviewed Mr. James F. Robertson on the subject this morning.

"Yes," said that gentleman, in response to the reporter's query; "we did experience a shock of an earthquake last night at Rothesay. It was exactly seven minutes past ten o'clock when I felt it. My house, which is built on what I might call quick sand, is peculiarly sensitive to anything like this. A train passing will cause all the windows to rattle, but the shock experienced last night was a trifle heavier than that caused by a train. It did not upset anything in my house, but Mr. Clinch's folks telephoned us that it had knocked down a box in their dwelling. Mr. John McMillan, who resides a short distance from Rothesay, did not feel the shock at his place."

Mr. R. T. Clinch was questioned regarding the matter. "About half-past ten," said Mr Clinch, "we felt the first shock. Our house was shaken so violently as to make everything rattle in it. Our beds shook, and a large box, which was on a mantel in one of the children's rooms upstairs, was thrown to the floor. About half an hour after that we felt another vibration, although not as heavy as the first. My servant man, whose house is a short distance from mine, felt it keenly. The house shook so violently as to damage the works of a clock on the mantel. He told me there was another shock about 4 o'clock this morning."

Mr. S. S. Hall, on whom the reporter called, stated that he also experienced a slight shock, but it was about 9:30. It was not at all heavy, his house vibrating just a little.

The theory is advanced that as the land on which the houses of Messrs. Clinch, Hall and Robertson are built is of sandy formation the shocks may have been the result of the action of frost.

It is seen from the above accounts of events felt at different times by different people that these were cryoseismic events and the earthquake listing for 26 January 1884 should be removed from the CEEF. Care should always be taken in evaluating events reported for the winter months, particularly when from only one locality, or when an event is reported from several locations at different times.

Another class of winter quakes is "icequakes": sharp sounds and high-frequency tremors caused by the fracturing of ice sheets on rivers or lakes. Studies by workers on Lake Michigan have shown an increase in activity is associated with changes in temperature and that the tremors are located in narrow linear zones (Willis *et al.*, 1978). An example of icequakes that were mistakenly identified as an earthquake is contained in the reports of events on 5 January 1893 in the 13 January issue of *Courrier des Provinces Maritimes*. The following report from Bathurst was found (translated from the French):

An earthquake is a very rare thing in the Maritime Provinces, but Thursday evening toward midnight, those citizens who were not yet asleep noticed a light earthquake. We do not have any damage to report.

A light shock was felt at Fredericton and the surroundings. The houses were shaken and the ice on the river, along a 3-mile distance, was broken and made impassable for travelers.

The report of a shock being felt on this date in the two communities of Bathurst and Fredericton, being about 250 km apart, suggested the possibility of a magnitude 4 or larger earthquake in the Central Highlands. Lateral searches of other newspapers in the province, however, found only versions of the following account from the *Fredericton Herald* issue of 7 January 1893, which clearly identifies the activity reported from Fredericton as being related to icequakes.

EARTHQUAKE

What was said to be an earthquake startled the people of Prince William and Kingsclear on Wednesday night. It is thought however to have been occasioned by the sudden shifting of ice by the increase of water due to Monday's rain. No damage was done.

It is concluded therefore that what was reported was two separate events: icequakes felt at Fredericton and other communities along the Saint John River, caused by the fracturing of the ice, and probable cryoseismic activity at Bathurst.

SEISMICITY OF THE SUBZONES

Central Highlands Subzone

The importance of the Central Highlands subzone (Figure 1) was brought to the attention of the seismological community by the 5.7 m_b Miramichi earthquake at 12:53 (UT) on 9 January 1982, with an epicenter of 47.0°N, 66.6°W (Basham *et al.*, 1982). The main earthquake was followed by a long sequence of aftershocks, including one of 5.1 m_b at 16:36 (UT) on the same day, another of 5.4 m_b at 21:41 (UT) on 11 January 1982, and one of 5.0 m_b at 21:02 (UT) on 31 March 1982. Indeed, of the more than 600 events listed in the CEEF since 1982, for a one-degree area around the epicenter, 575 are within a few kilometers of the epicenter of the main 9 January 1982 earthquake.

Our study of the historical seismicity of New Brunswick therefore commenced with scanning of newspapers that might report the occurrences of earthquakes in this remote and central part of the province. Because the region is occupied predominantly by an Acadian population, the French-language newspapers *Le Moniteur Acadien*, for the period 1867 to 1926, and *Le Courrier des Provinces Maritimes*, for the period 1885 to 1903, were scanned for references to earthquakes. The period 1906 to 1943 was covered by scanning the English-language newspaper the *North Shore Leader*, after a preliminary scanning of an originally chosen Acadian

newspaper, *Le Madawaska*, showed a lack of regional coverage of events such as earthquakes.

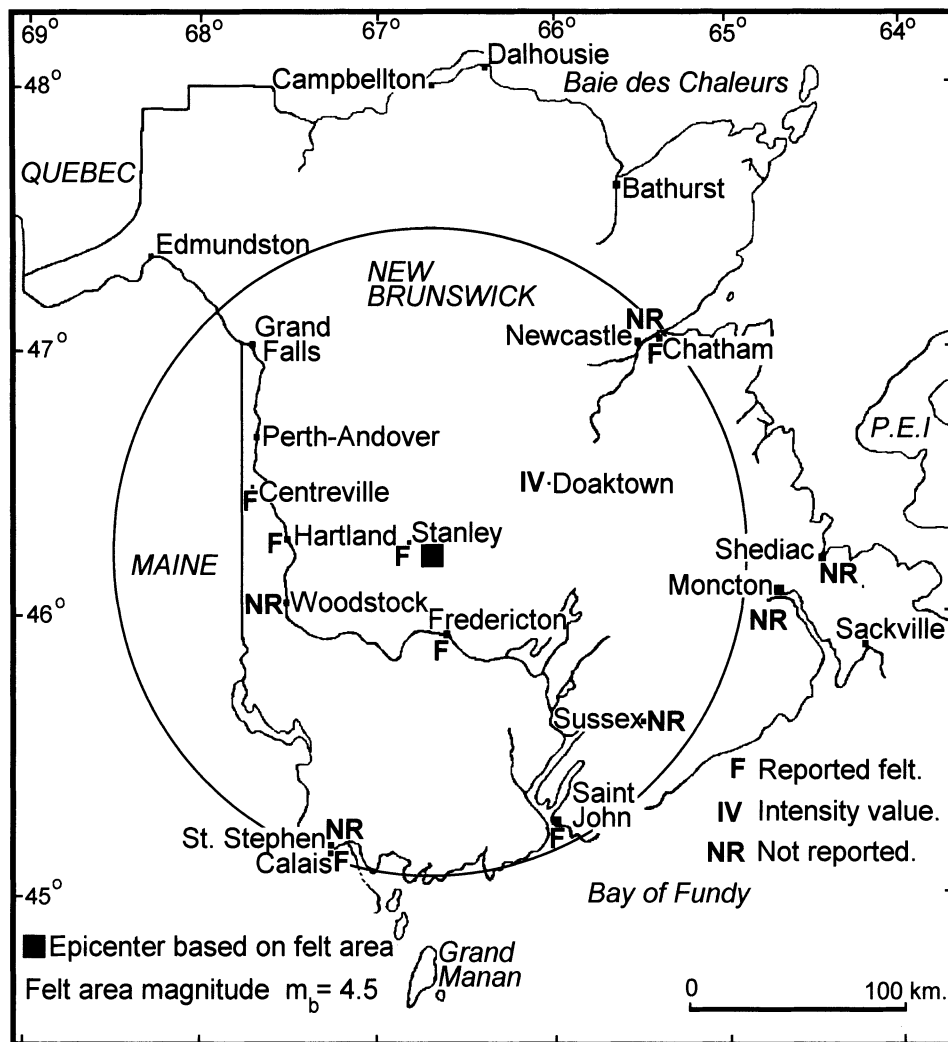
The scanning procedure found seven unlisted earthquakes in the Central Highlands subzone and several more in other parts of the province. A decision was therefore made to extend the timeframe of the project by using English-language newspapers: *The Mercury*, for the period 1826 to 1829, and *The Gleaner and Northumberland Scediasma*, for the period 1829 to 1867, and to continue scanning the *North Shore Leader* for the period 1944 to 1961. After 1961, seismograph coverage became available for New Brunswick. Scanning found four more unlisted earthquakes in the Central Highlands subzone and three events from elsewhere. This second study also included lateral searches of all available New Brunswick and Prince Edward Island newspapers and documents for references to Central Highlands earthquakes already listed in the CEEF, in addition to the previously unlisted events.

Table 1 shows a compilation of all the previously unlisted events found by the scanning procedure. Of the fourteen events listed, eleven have been identified and interpreted as earthquakes, while the three other small local events reported for winter months from single locations have been interpreted as cryoseisms or icequakes. Felt-area maps have been plotted for all of the earthquakes for which there are reports from more than one location and epicenters and felt-area

TABLE 1
Previously Unlisted Events in the Central Highlands Subzone 1824–1961

Date	Time	Location	Magnitude	Comments
18351130	AM?	46.8°N, 66.1°W	A	Small local earthquake, 15 miles up the Renous River, N.B.
18520926	20:30UT	46.0°N, 66.5°W	A	Small local earthquake, felt at Dalhousie and in parts of Restigouche County, N.B.
18630316	08:30UT	47.1°N, 65.5°W	4.0	Felt at Bathurst, Chatham, and Richibucto, N.B.
18630420	AM?	47.1°N, 65.5°W	A	Felt at Richibucto, N.B. Possible aftershock of 16 March 1863 earthquake.
18701206	01:54 AST			Shock felt only in Fredericton, N.B. Probably a cryoseism.
18740319	PM?			Slight shock felt only in Fredericton, N.B. Probably a cryoseism.
188309?	?	46.6°N, 66.1°W	A	Three shocks felt during the month of September 1883 at Doaktown, N.B.
18930105	Midnight?			Light shocks felt at Bathurst, Fredericton, Kingsclear, and Prince William, N.B. Probably a cryoseism at Bathurst. Shocks felt at other places are "icequakes" caused by thawing of river ice (see text).
19031218	02:00 UT	46.8°N, 66.2°W	4.2	Felt at Bathurst and Fredericton and along Nashwaak and Tobique valleys in N.B.
19040228	12:37 UT	47.5°N, 65.5°W	A	Felt at Bathurst and other parts of Gloucester County, N.B. Possible foreshock felt at 03:00 UT at Bathurst.
19110320	12:30 UT	46.4°N, 66.7°W	4.5	Felt at Calais, Maine and Centreville, Doaktown, Fredericton, Hartland, Saint John, and Stanley, N.B.
19110827	?	46.9°N, 65.6°W	A	Felt at Barnaby River and Millerton and in upper Miramichi River Valley, N.B.
19150627	14:25 UT	46.2°N, 67.0°W	3.8	Felt at Fredericton, Hartland, and Stanley and along the Nashwaak and Saint John River valleys, N.B.
19250330	18:10 UT	46.5°N, 66.0°W	4.1	Felt at Barnaby River, Chatham, Chelmsford, Fredericton, Millerton, Newcastle, Red Bank, and Rogersville, N.B.

Note: "A" denotes a magnitude in the range 2 to 3.



▲ **Figure 2.** Felt area map for 20 March 1911 earthquake.

magnitudes determined. Epicenters were placed at the centers of the felt areas and magnitudes were obtained using the felt-area relationships published by Nuttli and Zollweg (1974), Street and Lacroix (1979), Sibol *et al.* (1987), and EPRI (1994). The median value calculated from these relationships was selected as the representative value of magnitude.

As an example, the felt-area map for the 20 March 1911 earthquake is shown in Figure 2. This earthquake was reported felt at Centreville, Doaktown, Fredericton, Hartland, Saint John, and Stanley, New Brunswick and Calais, Maine. A circle was drawn on the map to surround all of the felt report locations, and the center of the circle at 46.4°N, 66.7°W is taken to represent the epicenter. An area of 103,410 km² was calculated as the area of the circle and a median value of magnitude of 4.5 obtained from the felt area–magnitude relationships.

Table 2 shows previously listed earthquakes for the Central Highlands subzone between 1824 and 1961 which require revision, based on information found in the lateral searches. Revisions of the epicenters and/or magnitudes are required for nine earthquakes as noted in bold text in Table 2.

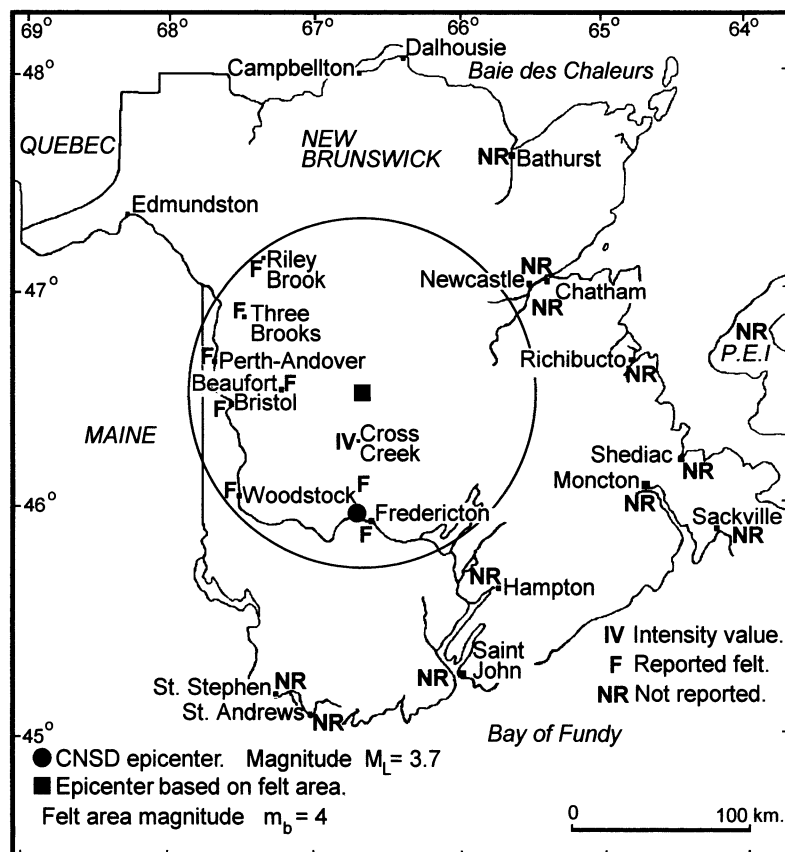
For example, the listed and revised epicenters for the 16 May 1896 earthquake are shown in the felt-area plot in Figure 3. This earthquake was reported felt at Beaufort, Bristol, Cross Creek, Fredericton, Riley Brook, and Upper Woodstock and along the Nashwak and Tobique valleys. Again, a circle was drawn on the map to surround all of the felt report locations and the center of the circle at 46.6°N, 66.8°W taken to represent the epicenter. An area of 23,779 km² was calculated as the area of the circle and a median value of magnitude of 4.0 obtained from the felt area–magnitude relationships. This more central location contrasts with an epicenter of 46.0°N, 66.6°W, just northwest of Fredericton, and a M_L of 3.7 in the CEEF. The epicenter of one earthquake, that of 9 July 1824, has been moved from a location in the Central Highlands subzone to the Passamaquoddy Bay subzone, because references to this earthquake in the newspapers of the day report it being felt only at the more southerly location of Eastport, Maine.

Damage reports and changes to spring water flow at more northerly locations, *e.g.*, Newcastle (Miramichi City), suggested the possibility to Leblanc and Burke (1985) that the 22 October 1869 earthquake might be in the Central

TABLE 2
Revisions to Events listed in the CEEF for the Central Highlands Subzone 1824–1961

Date	Time	Location	Magnitude	Comments
18240709	01:15 UT	46.5°N, 66.5°W 44.9°N, 67.0°W	4.3 A	Listed as in central N.B., but newspaper reports shock being felt only at Eastport, Maine. Epicenter and magnitude revised.
18520803	03:00 UT	47.6°N, 65.6°W 47.5°N, 65.8°W	3.0 M_L 3.8	Felt at Bathurst and Newcastle, and for 23 miles along the Bay of Chaleur, N.B. Epicenter and magnitude revised.
18691022	10:45 UT	45.0°N, 67.2°W 46.5°N, 66.5°W	5.7 M_N	Leblanc and Burke (1985) placed this earthquake in the Passamaquoddy Bay subzone, but additional evidence indicates a more central location (see text).
18960516	03:00 UT	46.0°N, 66.6°W 46.6°N, 66.8°W	3.7 4.0	Felt at Beaufort, Bristol, Cross Creek, Fredericton, Riley Brook, and Upper Woodstock, and in Nashwaak and Tobique valleys, N.B. Epicenter and magnitude revised.
19080808	11:00 UT	46.0°N, 67.0°W 46.5°N, 67.0°W	4.3 4.4	Felt at Bristol, Chatham, Fredericton, Grand Falls, Hartland, Keswick, and Woodstock and along upper Saint John Valley, N.B. Epicenter and magnitude revised.
19220722	22:25 UT	46.5°N, 66.6°W	4.3 M_L 4.9	Magnitude revised based on new felt reports from surrounding area.
19300104	14:10 UT	46.73°N, 65.8°W 46.7°N, 66.0°W	4.6 M_L 4.2	Felt at Blackville, Boistown, Chatham, Doaktown, Fredericton, Millerton, Nashwaak Village, Nelson, Newcastle, and Stanley and along Miramichi and Nashwaak Rivers, N.B. Epicenter and magnitude revised.
19301016	00:30 UT	46.54°N, 66.38°W 47.3°N, 65.6°W	2.3 M_L 3.6	Felt at Bathurst, Chatham, Loggieville, Millerton, and Newcastle, N.B. Epicenter and magnitude revised.
19370930	07:58 UT	45.47°N, 65.83°W 47.4°N, 66.3°W	5.0 M_L 4.8	Felt at Bathurst, Campbellton, Dalhousie, Fredericton, Kedgewick River, Moncton, and St. Martins, N.B. and the lower Gaspé, Québec. Epicenter and magnitude revised.

Notes: **Bold** text denotes revised locations and magnitudes. "A" denotes a magnitude in the range 2 to 3.



▲ **Figure 3.** Felt-area map for 16 May 1896 earthquake.

Highlands, although they finally positioned this earthquake in the Passamaquoddy Bay subzone. However, reports of aftershock activity being felt in the Fredericton area and a possible foreshock and aftershock being felt in the Tobique Valley in northwestern New Brunswick have been found. The 24 November 1869 issue of the *Saint Andrews Standard* states, "Several people in Fredericton affirm that there was a slight shock of an earthquake felt in the city on the morning of the 9th." Similarly, a letter to the editor appears in the 30 October 1869 issue of the *Carlton Sentinel*, from a correspondent who lived in the Tobique Valley at the time of the earthquake, which states, "It is said by some that there was a shock some six hours previous to the one spoken of, and also on Friday night, but they were slight." No reports of foreshocks or aftershocks were found from Passamaquoddy Bay locations in the newspapers, as might be expected if the epicenter had been located there, although such reports were found for the other large-magnitude earthquake in that region in 1904. It is therefore now believed that the evidence favors a Central Highlands location for the 1869 earthquake, and its epicenter has been changed to 46.5°N, 66.5°W.

Two of the earthquakes studied had large felt areas that extended outside of the province. These earthquakes on 2 July 1922 and 30 September 1937 should therefore be subjected to further lateral searches in the newspapers and historical documents of adjacent provinces and New England states to refine the determination of their epicenters and felt-area magnitudes.

Passamaquoddy Bay Subzone

Two earthquakes of larger than magnitude 5 are included in the CEEF for the Passamaquoddy Bay subzone (Figure 1):

the 5.7 m_N earthquake on 22 October 1869 and a 5.9 m_N earthquake on 21 March 1904. In addition, another 24 earthquakes of lower magnitudes are listed in the CEEF for this region between 1817 and 1961.

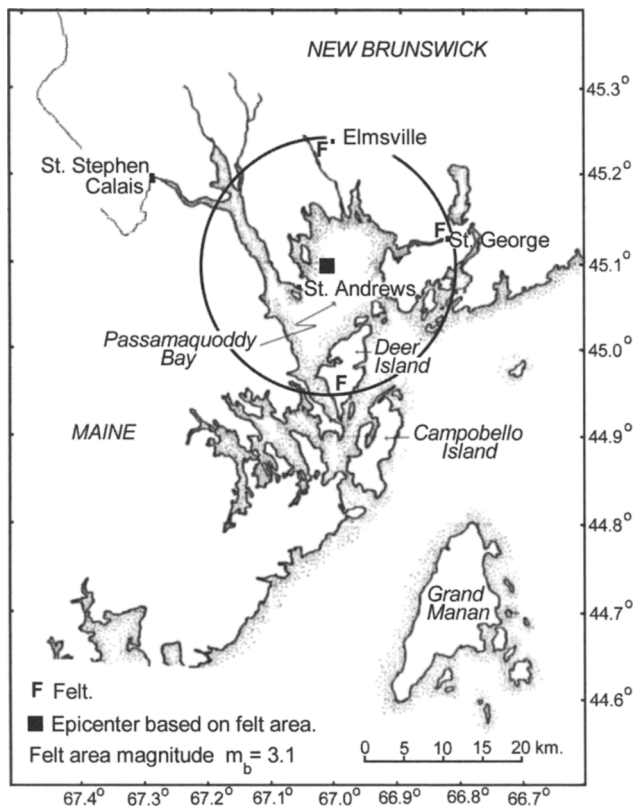
A study of the historical seismicity of the Passamaquoddy Bay subzone was made by scanning microfilm copies of the *New Brunswick Courier* for the period 1811 to 1865, the *St. Andrews Standard* for the period 1833 to 1865, and the *St. Croix Courier* for the period 1865 to 1961. The latter newspaper, published in St. Stephen, has an excellent coverage of local news for the communities in the area. This scanning procedure found thirteen previously unlisted events in the Passamaquoddy Bay subzone and three more in other parts of the province for the period 1817 to 1961. Lateral searches were made of all available New Brunswick newspapers that might mention these events and for the dates of those earthquakes listed in the CEEF. Dates in the period 1811 to 1900 were also checked in a Maine newspaper, the *Eastport Sentinel*, for issues which are available on microfilm.

Table 3 shows the events found by the scanning procedure that were not listed in the CEEF, although three had been previously found by Smith *et al.* (1989). Of the thirteen events, eleven have been identified and interpreted as earthquakes, while two small local events, reported for winter months from just one location, are interpreted as probable cryoseisms. Epicenters and felt-area magnitudes for the earthquakes were determined using the same procedure as in the study of the Central Highlands earthquakes. As an example, the felt-area map for the 25 February 1935 earthquake is shown in Figure 4. This earthquake was reported felt at Elmsville and St. George, and on Deer Island. An area of

TABLE 3
Previously Unlisted events in the Passamaquoddy Bay Subzone 1811–1961

Date	Time	Location	Magnitude	Comments
18190721	?	44.9°N, 67.0°W	A	Slight earthquake shock felt at Dennysville, Maine. Ref: Smith <i>et al.</i> (1989).
18291118	02:00 UT	45.1°N, 67.0°W	A	Small local earthquake felt at St. Andrews, N.B.
18610125	21:00 UT	44.7°N, 67.3°W	A	Felt at Eastport and Steuben, Maine. Ref: Smith <i>et al.</i> (1989)
18611023	12:05 UT	45.2°N, 67.3°W	A	Felt at St. Stephen, N.B. and Calais, Maine.
18620124	01:30 UT			Felt only at Pembroke, Maine. Ref: Smith <i>et al.</i> (1989). Probably a cryoseism because of winter date.
18630220	"night"			Slight shock reported felt only at Eastport, Maine. Winter date suggests this event was probably a cryoseism.
18630605	09:00 UT	45.1°N, 67.0°W	A	Felt at St. Andrews, N.B.
18651007	04:30 UT	45.2°N, 67.3°W	A	Felt at St. Stephen, N.B.
18670424	19:00 UT	45.2°N, 67.3°W	A	Felt at St. Stephen, N.B.
18840322	04:00 UT	45.2°N, 67.3°W	A	Felt at Old Ridge and in parts of St. Croix Parish, N.B. and Calais, Maine.
19070219	21:30 UT	45.2°N, 67.1°W	A	Felt at St. George and St. Stephen, N.B. Second event 20 minutes later at St. George.
19350225	00:32 UT	45.1°N, 67.0°W	3.2	Felt on Deer Island and at Elmsville and St. George, N.B.
19371023	03:00 UT	45.2°N, 67.3°W	A	Felt in St. Croix Valley in N.B. and at Calais, Maine.

Note: "A" denotes a magnitude in the range 2 to 3.



▲ **Figure 4.** Felt-area map for 25 February 1935 earthquake.

1,018 km² was calculated as the area of the circle and a median value of magnitude of 3.2 obtained from the felt area–magnitude relationships. The center of the circle places the epicenter in Passamaquoddy Bay at 45.1°N, 67.0°W.

Table 4 shows 24 previously listed earthquakes for the Passamaquoddy Bay subzone between 1811 and 1961 that require revisions based on information found in the lateral searches. In addition, a 9 July 1824 earthquake, which previously had been mistakenly listed in the central part of the province, and the 30 January 1851 quake which previously had been listed as occurring at St. Andrews in the province of Québec, have been moved into the Passamaquoddy Bay subzone. Newspaper accounts clearly identify this latter event as a local earthquake felt at St. Andrews, New Brunswick and at other local communities in the Passamaquoddy Bay region. An event on 9 April 1931, previously listed as an earthquake, was reported in the 10 April 1931 issue of the *Evening Times Globe* as a dynamite explosion on Deer Island and should be removed from earthquake listings. Four events, on 28 January 1897, 14 February 1897, 11 January 1898, and 20 March 1912, were reported only from single locations during winter months and are interpreted as probable cryoseisms.

As discussed in the previous section, the 22 October 1869 earthquake has been moved from the Passamaquoddy Bay subzone to the Central Highlands subzone and the 9 July 1824 has been moved from the Central Highlands subzone to the Passamaquoddy Bay subzone. The earthquake listed for 31 December 1882, besides requiring a revision of time and

date, is also probably mislocated in the Passamaquoddy Bay region. Ruffman and Peterson (1988) included many felt reports from Nova Scotia locations for this earthquake, some of which indicate that more than one shock was felt from this event. Reports of multiple shocks are also contained in accounts in some of the U.S. newspapers, indicating a large earthquake with aftershocks. Ruffman and Peterson (1988) suggest an offshore location on the Scotian Shelf for this event, and the present study has obtained a preliminary epicenter of 42°N, 64.0°W and a magnitude of 5.3 based on a felt-area map. This earthquake should be subjected to more extensive research of newspapers and other documents over a wider area.

Of the remaining nineteen events listed, revisions of the epicenters and/or magnitudes are required for eighteen earthquakes and revisions of time and/or date are needed for nine earthquakes, as noted in bold text in Table 4. For example, the listed and revised epicenters for the 22 February 1873 earthquake are shown in the felt-area plot in Figure 5. This earthquake was reported felt at St. David, St. George, St. Stephen, and Waweig, New Brunswick and Eastport and Lubec, Maine. Again, a circle was drawn on the map to surround all of the felt report locations, and the center of the circle, at 45.1°N, 67.0°W, taken to represent the epicenter, rather than at Eastport, Maine, as listed by Smith *et al.* (1989). An area of 1,886 km² was calculated as the felt area and a median value of magnitude of 3.3 obtained.

On 2 January 1999, a M_N 2.3 earthquake occurred in the Passamaquoddy Bay region, and felt information was collected by e-mail and telephone from some of the residents in the area, as well as from the *St Croix Courier*. This earthquake was felt at Bocabec Cove, Milltown, St. Andrews, and St. Stephen in New Brunswick and at Calais, Maine. As a test of the procedure of determining the epicenter and magnitude from the felt area, this information is plotted in Figure 6. The plot shows a shift of 13 km to the northwest from the instrumentally determined epicenter and an increase from M_N 2.3 to m_b 3.2 in magnitude is noted. The difference in the epicentral position is within the uncertainty of instrumentally determined epicenters in this region. The overestimate of almost one magnitude unit, however, indicates that the extrapolation of the felt area–magnitude relationships to small magnitudes can lead to large errors in this parameter. For this reason, a magnitude range of 2 to 3 has been given for those not-instrumentally recorded earthquakes that are included in the tables when the felt-area magnitude is less than 3.3.

Moncton Subzone

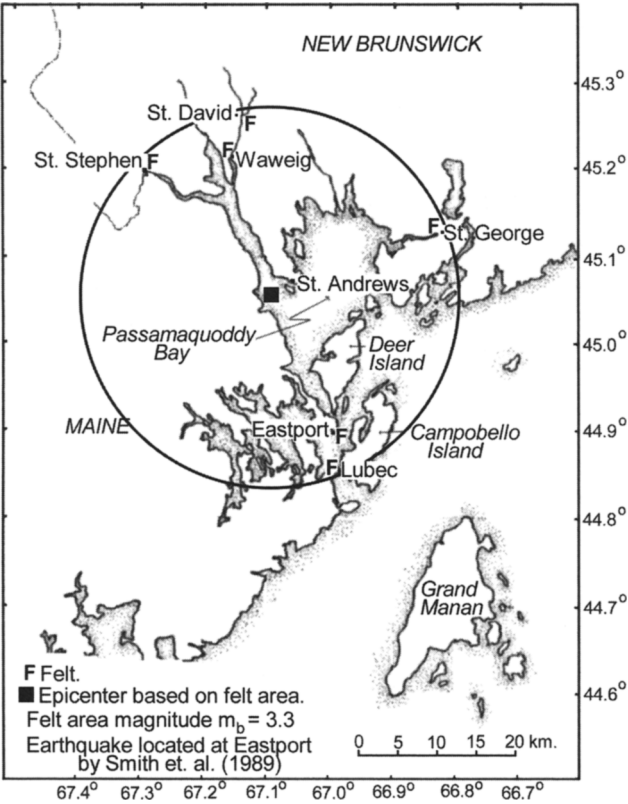
An 8 February 1855 earthquake was reported by Dawson (1868) to have occurred at “the bend of the Petitcodik”, the nineteenth-century name for the Moncton region (Figure 1) in southeastern New Brunswick. This earthquake was felt throughout most of New Brunswick and parts of Nova Scotia and as far southwest as Boston, Massachusetts. A magnitude of M_N 5.2, based on the area within the IV isoseismal (Leb-

TABLE 4
Revisions to Events Listed in the CEEF for the Passamaquoddy Bay Subzone 1811–1961

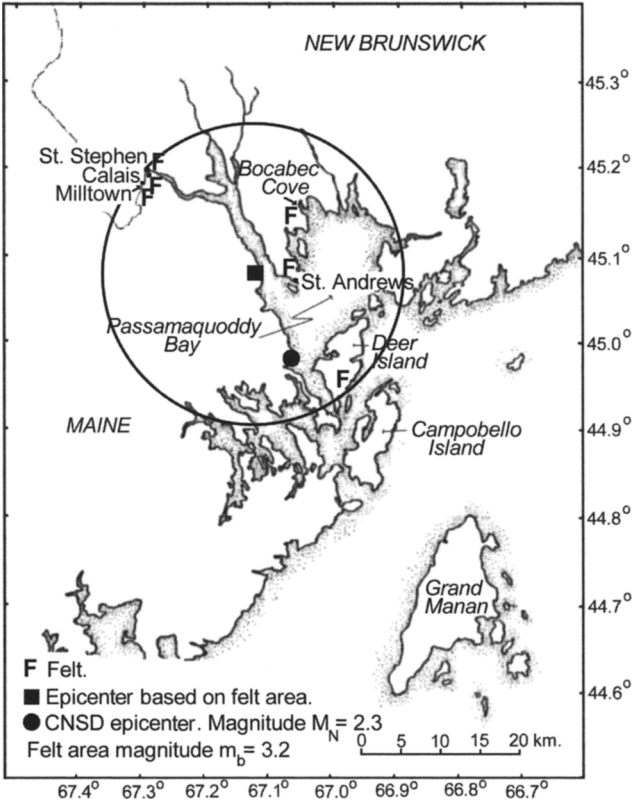
Date	Time	Location	Magnitude	Comments
18170522	20:00 UT 07:31 UT	45.0°N, 67.2°W	4.8 M_N	Newspaper reports give time of event as 3:31 AM (AST). Time revised.
18240709	01:15 UT	46.5°N, 66.5°W 44.9°N, 67.0°W	4.3 M_L A	Listed as in central N.B., but newspapers report shock being felt only at Eastport, Maine. Epicenter and magnitude revised.
18510130	22:00 UT 21:30UT	45.6°N, 74.3°W 45.1°N, 67.2°W	3.0 M_L 3.4	Listed in CEEF as an event at St. Andrews in Québec, but reported in newspapers as felt on Campobello Island and at Milltown and St. Andrews, N.B. and Eastport, Maine. Time, epicenter, and magnitude revised.
18691022	10:45 UT	45.0°N, 67.2°W 46.5°N, 66.5°W	5.7 M_N	Leblanc and Burke (1985) placed this earthquake in the Passamaquoddy Bay subzone, but additional evidence indicates a more central location (see text).
18730222	00:00 UT 11:30UT	44.9°N, 67.0°W 45.1°N, 67.0°W	3.0 M_L 3.3	Felt at St. David, St. George, St. Stephen, and Waweig, N.B. and Eastport, Maine. Time, epicenter, and magnitude revised.
18761120	00:00 UT 16:45UT	44.9°N, 67.0°W 44.8°N, 67.2°W	2.4 M_L 3.3	Felt at Eastport and Machias, Maine. Ref: Smith <i>et al.</i> (1989). Time, epicenter, and magnitude revised.
18821231 18830101	00:00 UT 02:15UT	45.0°N, 67.0°W 42°N, 64°W	4.3 M_L 5.3	Felt at many locations in Maine, New Brunswick, and Nova Scotia (see text). Date, time, epicenter, and magnitude revised.
18960322 18960323	00:00 UT 02:45UT	45.2°N, 67.2°W 45.3°N, 67.5°W	4.0 M_L 4.2	Felt at Beaver Harbour, Grand Manan, McAdam, Moores Mills, Oak Bay, Pennfield, St. Andrews, St. George, St. Stephen, Welshpool, Wilson's Beach, and Woodstock, N.B. and Calais and Machias, Maine. Date, time, epicenter, and magnitude revised.
18970126	00:00 UT 15:30UT	44.9°N, 66.9°W 45.0°N, 67.2°W	3.0 M_L 3.5	Felt on Campobello and Deer Islands, N.B. and at Calais and Machias, Maine. Time, epicenter, and magnitude revised.
18970128	00:00UT	44.5°N, 66.8°W	3.7 M_L	Felt only on Grand Manan, N.B. Winter date and single report from one location indicate that event is probably a cryoseism.
18970214	00:00UT	44.7°N, 66.8°W	3.0 M_L	Felt only on Grand Manan, N.B. Winter date and single report from one location indicate that event is probably a cryoseism.
18971012 18971013	00:00UT 02:35UT	44.7°N, 66.8°W	3.0 M_L A	Felt on Grand Manan, N.B. Date, time, and magnitude revised.
18980111	09:00 UT 07:31 UT	44.7°N, 66.8°W	3.0 M_L	Felt only on Grand Manan, N.B. Winter date and single report from one location indicate event is probably a cryoseism.
19120320	12:00 UT	45.2°N, 67.3°W	3.0 M_L	Felt only at Calais, Maine. Winter date and single report from one location indicate event is probably a cryoseism.
19121211	10:15 UT	45.0°N, 68.0°W	4.0 M_L 4.7	Felt extensively throughout southwestern New Brunswick and southeastern Maine. Magnitude revised based on felt area.
19140113	08:00 UT	45.1°N, 67.2°W 45.6°N, 66.9°W	4.4 M_L 3.9	Felt at Fredericton, Fredericton Junction, and St. Stephen, N.B. and Calais, Maine. Epicenter and magnitude revised.
19180114	07:20 UT	45.0°N, 67.3°W 45.1°N, 67.1°W	3.7 M_L 3.3	Felt at Calais and Eastport, Maine. Epicenter and magnitude revised.
19201109	00:40 UT	45.0°N, 67.1°W 45.4°N, 67.4°W	3.7 M_L 3.3	Felt at Milltown, N.B. and Eastport, Maine. Epicenter and magnitude revised.
19211010	13:00 UT	44.8°N, 67.0°W 45.0°N, 67.0°W	3.7 M_L A	Felt at Back Bay and on Campobello Island, N.B. and at Perry and Pembroke, Maine. Epicenter and magnitude revised.
19261124	19:30 UT 18:30 UT	45.0°N, 67.5°W 45.0°N, 67.0°W	3.7 M_L 3.0	Felt at Milltown and St. Stephen, N.B. and Eastport, Perry, and Pembroke, Maine. Time, epicenter, and magnitude revised.
19281120	02:30 UT	45.0°N, 67.2°W 44.9°N, 67.0°W	3.6 M_L A	Felt on Deer Island, N.B. and at Eastport and Pembroke, Maine. Epicenter and magnitude revised.
19310409	00:00 UT	45.0°N, 67.0°W	3.0 M_L	Later reported as a dynamite explosion in newspaper (see text). Not an earthquake.

Notes: **Bold** text denotes revised dates, times, epicenters, and magnitudes. "A" denotes a magnitude in the range 2 to 3.

TABLE 4 (Continued) Revisions to Events Listed in the CEEF for the Passamaquoddy Bay Subzone 1811–1961				
Date	Time	Location	Magnitude	Comments
19340826	11:36 UT	44.9°N, 67.0°W 44.95°N, 67.0°W	3.0 M_L A	Felt on Deer Island, N.B. and at Eastport, Maine. Epicenter and magnitude revised.
193503204	02:40 UT	44.9°N, 67.0°W 44.95°N, 67.0°W	3.0 M_L A	Felt on Deer Island, N.B. and at Eastport, Maine. Epicenter and magnitude revised.
19450715	10:44:59 UT	44.9°N, 67.0°W 45.0°N, 67.3°W	4.6 M_L 3.5	Felt on Deer Island and at St. Stephen, N.B. and at Calais, Machias, Pembroke, and Woodland, Maine. Epicenter and magnitude revised.
19481121	15:41 UT	44.9°N, 67.0°W	3.0 M_L	Felt at Black's Harbour and Milltown, N.B. and Eastport, Maine. Epicenter and magnitude revised.
Notes: Bold text denotes revised dates, times, epicenters, and magnitudes. "A" denotes a magnitude in the range 2 to 3.				



▲ **Figure 5.** Felt-area map for 22 February 1873 earthquake.



▲ **Figure 6.** Felt-area map for 2 January 1999 earthquake.

lanc and Burke, 1985), and an epicenter given by Smith (1962) of 46.0°N, 64.5°W are listed in the CEEF for this earthquake. Another 24 smaller earthquakes are also listed in the CEEF, but 23 of these occurred after 1961, and most were detected only after the installation of seismograph LMN at Caledonia Mountain in 1984.

Although no Moncton newspapers were scanned as part of this study, it is believed that most felt earthquakes in the region would have been reported in the newspapers scanned for the Central Highlands subzone. Indeed, the French-language newspaper *Le Moniteur Acadien*, scanned for the period

1867 to 1926, was published in Shediac, which is in the northern part of the Moncton region. Three other newspapers, *The Mercury*, *The Gleaner and Northumberland Scediasma*, and the *North Shore Leader*, also contained news reports from along the northeast coast of New Brunswick, which would be part of the felt area from any earthquake with a magnitude larger than 3 in the Moncton region.

Scanning of the above newspapers found three previously unreported events in the Moncton region. In addition, lateral searches of newspapers for dates after the 1855 earthquake found references to four felt aftershocks in the month

TABLE 5 Previously Unlisted Events in the Moncton Subzone 1855–1961				
Date	Time	Location	Magnitude	Comments
18550210	At daylight (~11.00 UT)	46.0°N, 64.5°W	A	Aftershock from 8 February 1855 Moncton 5.2 M_N magnitude earthquake, as reported in local newspapers.
18550222	21:30 UT	46.0°N, 64.5°W	A	Aftershock from 8 February 1855 Moncton 5.2 M_N magnitude earthquake, as reported in local newspapers.
18550224	06:00–07:00 UT	46.0°N, 64.5°W	A	Aftershock from 8 February 1855 Moncton 5.2 M_N magnitude earthquake, as reported in local newspapers.
18550228	18:00 UT	46.0°N, 64.5°W	A	Aftershock from 8 February 1855 Moncton 5.2 M_N magnitude earthquake, as reported in local newspapers.
18670812	03:00 UT	46.1°N, 64.9°W	3.7	Felt at Barchois, Buctouche, Harvey, Hillsborough, Hopewell Corner, Moncton, Sackville, and Shediac, N.B.
18701222	1, 3, 5 AM local time			Light shocks reported felt at Moncton, N.B., and also by a few people at Richibucto and Newcastle, but at three different times. Probably cryoseismic activity.
18990620	03:30 UT	46.2°N, 64.7°W	A	Earthquake felt at Moncton and Shediac, N.B.
Note: “A” denotes a magnitude in the range 2 to 3.				

TABLE 6 Revisions to Events Listed in the CEEF for the Moncton Subzone 1855–1961				
Date	Time	Location	Magnitude	Comments
18240208	11:30 UT 10:45 UT	46.0°N, 64.5°W	5.2 M_N	Newspaper reports say earthquake was felt between 6:30 AM and 7:00 AM local time. Time revised.
19611031	23:50 UT	46.1°N, 64.78°W	1.7 M_L	From newspaper accounts and the lack of a seismograph recording at Halifax, N.S., this event is probably thunderstorm activity, rather than an earthquake. This event should be removed from the CEEF.
Note: Bold text denotes revised time.				

TABLE 7 Summary of Unlisted Events and Revisions to Listed Earthquakes 1817–1961					
Subzone	Unlisted Events		Listed Events		
	Earthquake	Nonearthquake	Moved	Parameters Revised	Deletions
Central Highlands	11	3	3	6	
Passamaquoddy Bay	11	2	4	17	5
Moncton	6	1		1	1

of February. The above information is listed in Table 5. An event on 22 December 1870 was reported at different times in the three communities and probably represents cryogenic activity on this date. The other two events appear to be small-magnitude earthquakes, similar to the two Turtle Creek earthquakes which were recorded in 1984 and 1988.

Table 6 shows the two previously listed earthquakes for the Moncton region between 1855 and 1961, with revisions based on information found in lateral searches. The time of the 8 February 1855 needs to be changed in the CEEF from 11:30 UT to 10:45 UT. From the newspaper reports and the lack of a seismograph reading at Halifax, it is probable that the 31 October 1961 event was thunderstorm activity rather

than an earthquake, and this event should therefore be removed from the CEEF.

SUMMARY AND DISCUSSION

A summary of unlisted events and revisions to events listed in the CEEF is given in Table 7. Twenty-eight previously unlisted earthquakes have been found and should be added to the CEEF. For the events already listed in the CEEF, the parameters of 24 earthquakes need to be revised. The major revisions are the 9 July 1824 earthquake moved from the Central Highlands subzone to the Passamaquoddy Bay subzone; the 22 October 1869 and 30 September 1937 earth-

quakes moved from southern New Brunswick into the Central Highlands subzone; the 1 January 1883 earthquake moved from the Passamaquoddy Bay subzone to offshore Nova Scotia; and the 30 January 1851 earthquake, previously reported to have occurred close to Saint Andrews, Québec, now known to be a local earthquake close to Saint Andrews, New Brunswick and moved to the Passamaquoddy Bay subzone. Six events, previously listed as earthquakes, were found to be more consistent with other phenomena and should be removed from the CEEF.

The list of earthquakes (1824 to 1961) for the Central Highlands subzone is believed to be complete for earthquakes with magnitudes greater than 4. Earthquakes in the magnitude 3 to 4 range have been reported occasionally, but because the Central Highlands subzone covers a large area, and the population is spread out mainly around its periphery, some earthquakes in this range have probably gone unreported. This latter idea is supported by a report in a newspaper in 1906 of hunters reporting rumbling sounds and feeling the earth shake at Bald Mountain in a remote part of the region, although no reports of earthquake shaking came from the nearest close-by communities.

The list of earthquakes (1817 to 1961) for the Passamaquoddy Bay region is believed to be complete for earthquakes with magnitudes greater than 3.3. This is because we are dealing with a much smaller area and the population lives in many small local communities spread throughout the region. A local newspaper, the *St. Stephen Courier*, also carried extensive reports in each issue from these communities, and we have the evidence of a 2.3 magnitude earthquake being reported felt in its columns in 1999. The problem with this list is the uncertainty in assigning correct magnitudes at the low end of the magnitude range, because as is seen for the 1999 earthquake, magnitude 2 earthquakes can alias as magnitude 3 earthquakes if we use the felt area–magnitude relationships to calculate magnitude.

The list of earthquakes (1855 to 1961) for the Moncton Region is believed to be complete for earthquakes with magnitudes greater than 3.3. Again we are dealing with a much smaller area with a reasonably spread-out population.

CONCLUSIONS

The scanning of weekly newspapers led to the discovery of 34 previously unlisted events of a possible seismic nature in the Central Highlands, Passamaquoddy Bay, and Moncton subzones. Lateral searches of other newspapers and historical documents for these events led to the conclusion that 28 of these events were earthquakes, while six events were identified as probable cryoseisms or icequakes. Similar lateral searches for the dates of earthquakes listed in the CEEF were responsible for the revision of epicenters, magnitudes, dates, and/or times for 30 earthquakes. Five events previously identified as earthquakes were found to be probable cryoseisms, one event was a dynamite blast, and one event can be explained by thunderstorm activity.

Earthquake activity was most frequent in the Central Highlands and Passamaquoddy Bay subzones during most of the nineteenth century and the first two thirds of the twentieth century, with a reduced amount of activity in the Moncton subzone. At least one magnitude 5 or greater earthquake has occurred in each region during this time. Based on the population distribution in the province of New Brunswick, it is believed that the earthquake record is now complete for magnitude 3.3 or greater earthquakes in the Moncton subzone since 1826 and the Passamaquoddy Bay subzone since 1833, and for magnitude 4 or greater earthquakes in the Central Highlands subzone since 1826.

Examination of the felt-area data from an instrumentally recorded earthquake in 1999 in the Passamaquoddy Bay region showed that this information overestimated the magnitude by 0.9 of a magnitude unit. Caution should therefore be exercised in applying the felt area–magnitude relationship to small earthquakes. Magnitudes for these small earthquakes have therefore been reported as having a range of 2 to 3, rather than being listed with a specific felt-area magnitude.

The earthquakes on 2 July 1922 and 30 September 1937, in the Central Highlands subzone, should be subjected to further lateral searches in the newspapers and historical documents of adjacent provinces and the New England states to determine their epicenters and felt-area magnitudes better. Similarly, the 1 January 1883 earthquake, moved from Passamaquoddy Bay to offshore Nova Scotia, should be subjected to more extensive research in other records. ☒

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